Jet Propulsion Laboratory
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UAVSAR Tomographic Calibration

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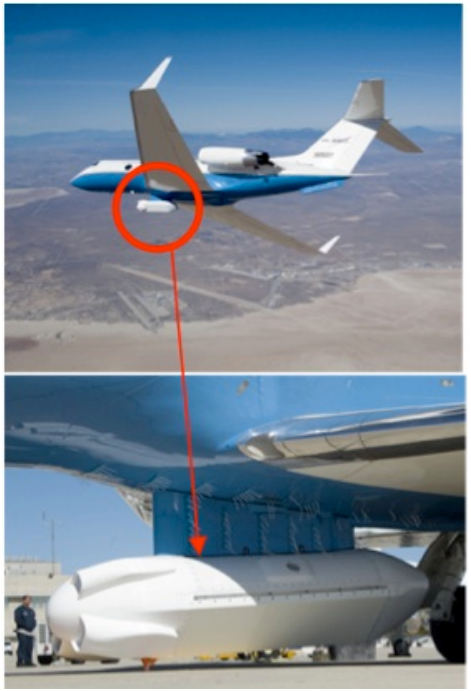
UAVSAR: L-Band, Airborne, Repeat Pass SAR



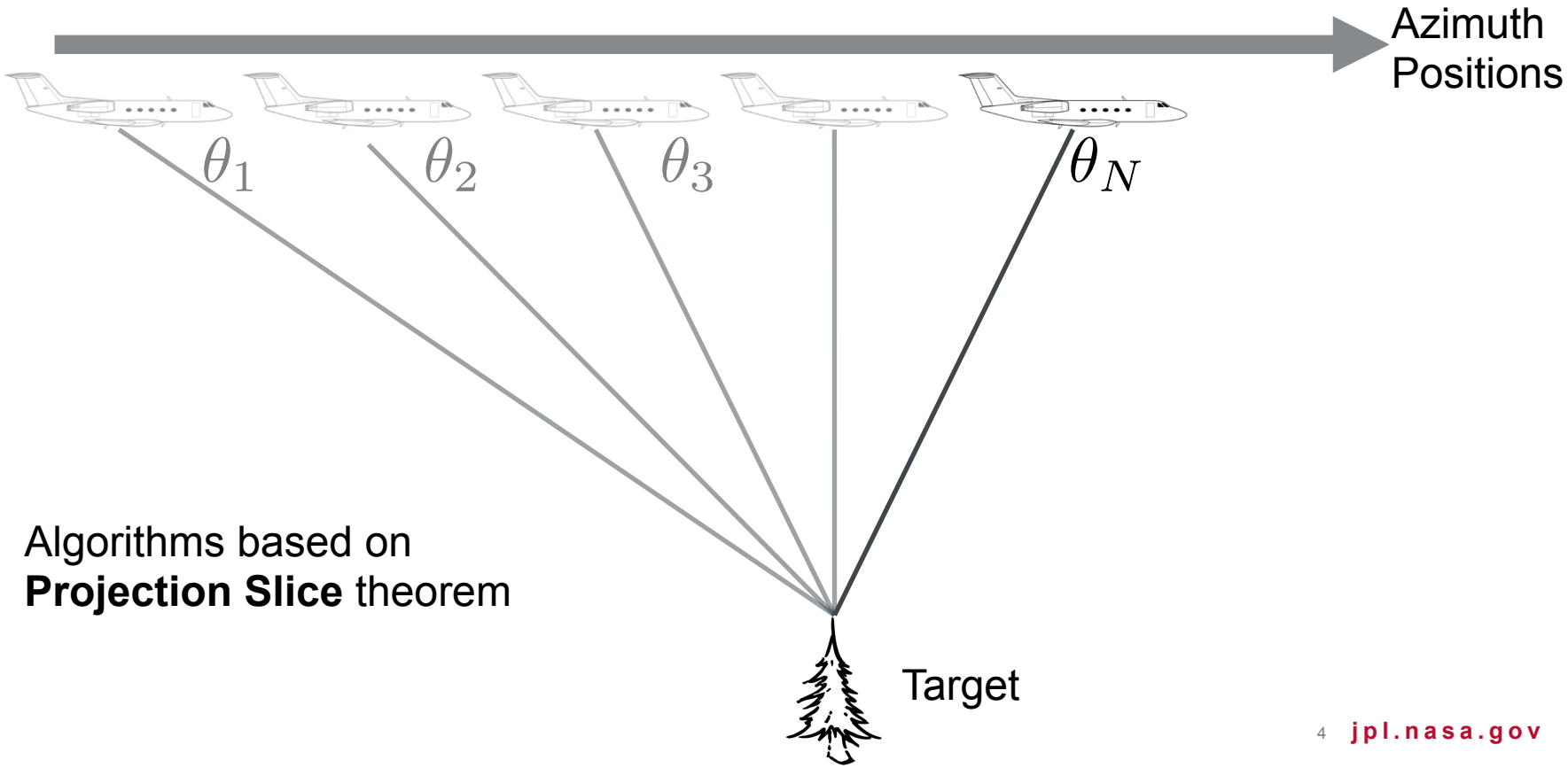
Frequency (MHz)	1257.5
Nominal bandwidth (MHz)	80
Nominal slant range resolution (m)	1.8
Azimuth resolution (m)	0.8
Polarization	Quad-pol
Nominal altitude (km)	12.5
Pulse length (μs)	5-50
Peak transmit power (kW)	3.1
Nominal spatial posting (m)	6
Nominal range swath (km)	22
Look angle range	25 - 65°
Noise equivalent σ (dB)	< -50

UAVSAR Deployed to Gabon in 2016

- Part of muti-agency AfriSAR campaign.
- Two sites designed for tomographic imaging
  - Rabi Forest
  - Lopé National Park

What's Tomographic SAR?

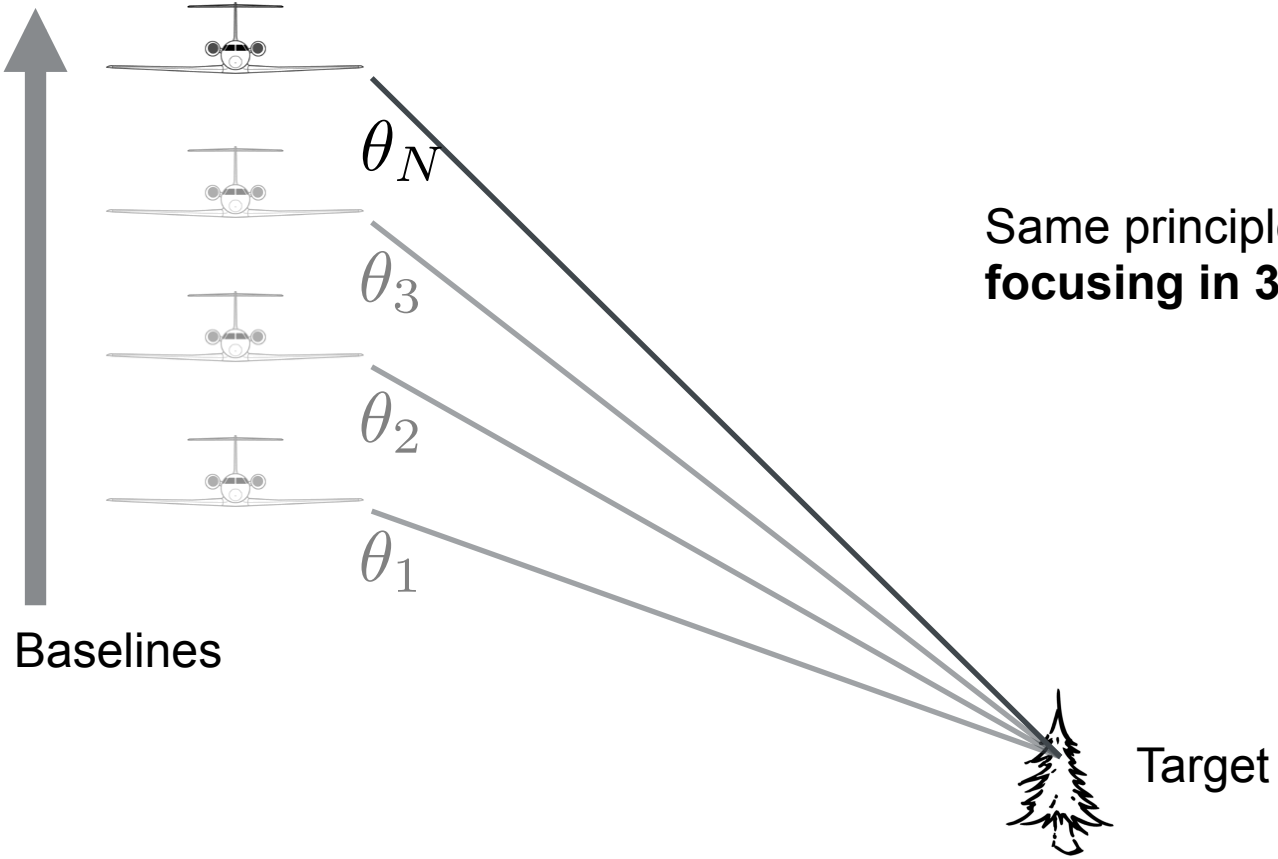
SAR: Synthetic Aperture Processing in Azimuth



Algorithms based on
Projection Slice theorem

What's Tomographic SAR?

Tomography: Synthetic Aperture Processing in Elevation



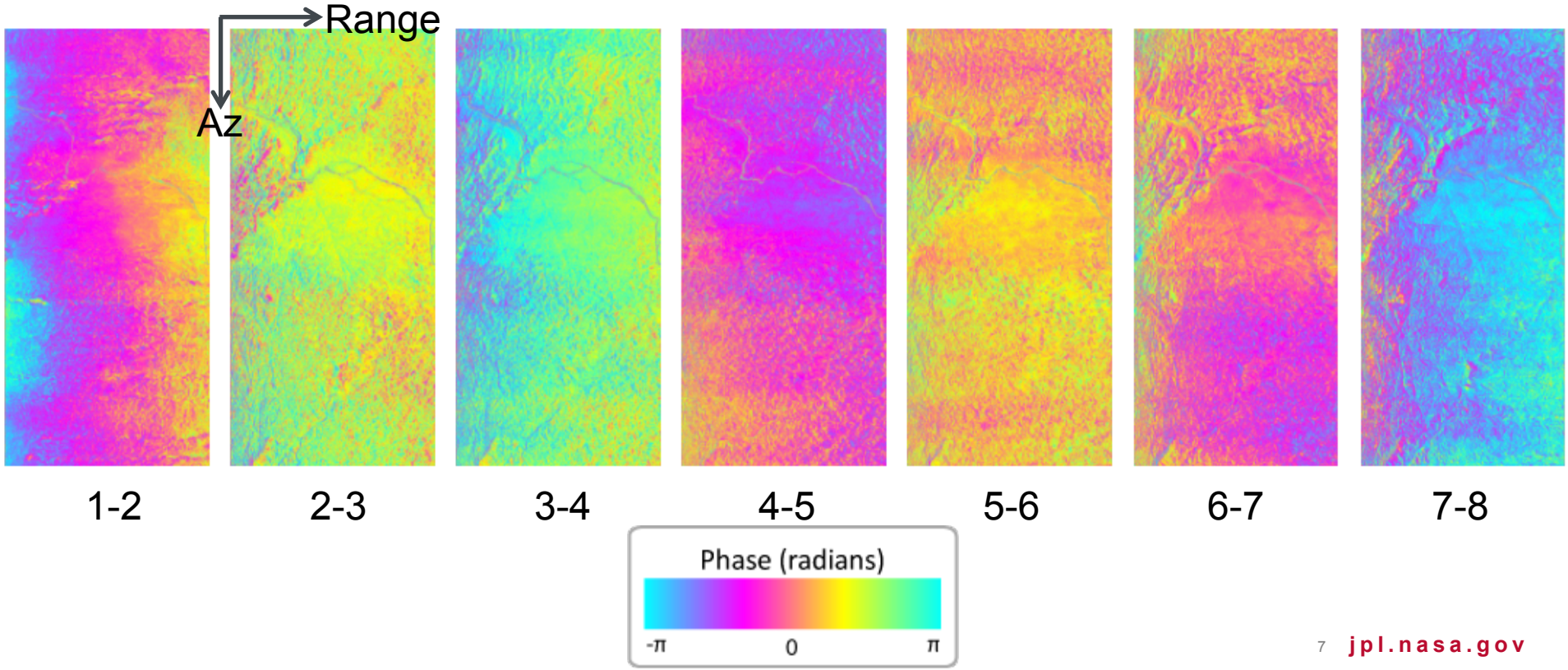
Same principles enable
focusing in 3D

Data Properties Needed for Focusing

- SAR
  - Azimuth beam width determines required azimuth sampling $\Delta\theta$ (PRF)
- Tomography
  - Volume thickness determines required baseline sampling $\Delta\theta$
- Both
  - Resolution related to total aperture length θ_N-θ_1
  - **Need stable phase for coherent processing**

Phase Stability

Repeat pass interferograms processed to reference DEM (B≈20 m)



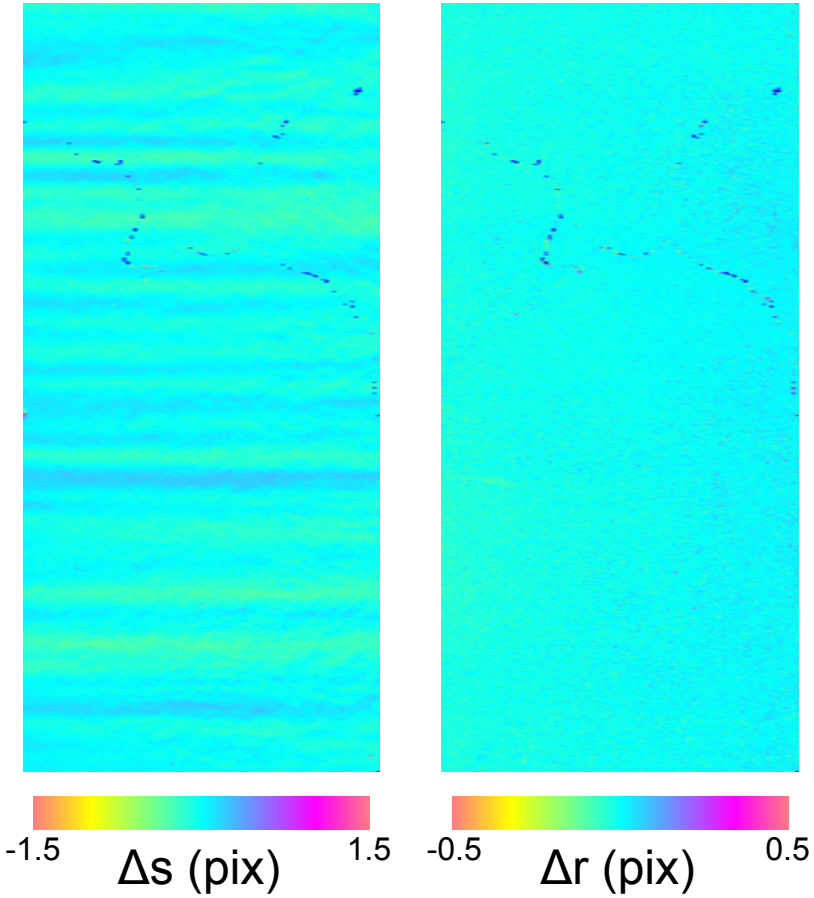
Phase Stability

- Absolute interferometric phase error okay for some applications, but **wrecks tomography**
- Typical causes of error
  - **Baseline** measurement errors
  - **DEM** errors
  - Atmospheric effects

Calibration

- First use simple extension of UAVSAR repeat-pass calibration procedure to refine baseline and improve coregistration.
  - S. Hensley et al., "Residual motion estimation for UAVSAR: Implications of an electronically scanned array," 2009 IEEE Radar Conference, Pasadena, CA, 2009, pp. 1-5.
- Second use “linked phases” to further refine baseline solution and DEM.
  - S. Tebaldini, F. Rocca, M. Mariotti d'Alessandro and L. Ferro-Famil, "Phase Calibration of Airborne Tomographic SAR Data via Phase Center Double Localization," in IEEE Transactions on Geoscience and Remote Sensing, vol. 54, no. 3, pp. 1775-1792, March 2016.

Step 1: Invert pixel offsets for baseline and reprocess



Straightforward extension of UAVSAR InSAR baseline calibration. Form N-1 adjacent pairs and measure pixel registration offsets. Solve relative baseline errors.

$$\Delta r \approx \Delta\vec{b} \cdot \hat{l}$$

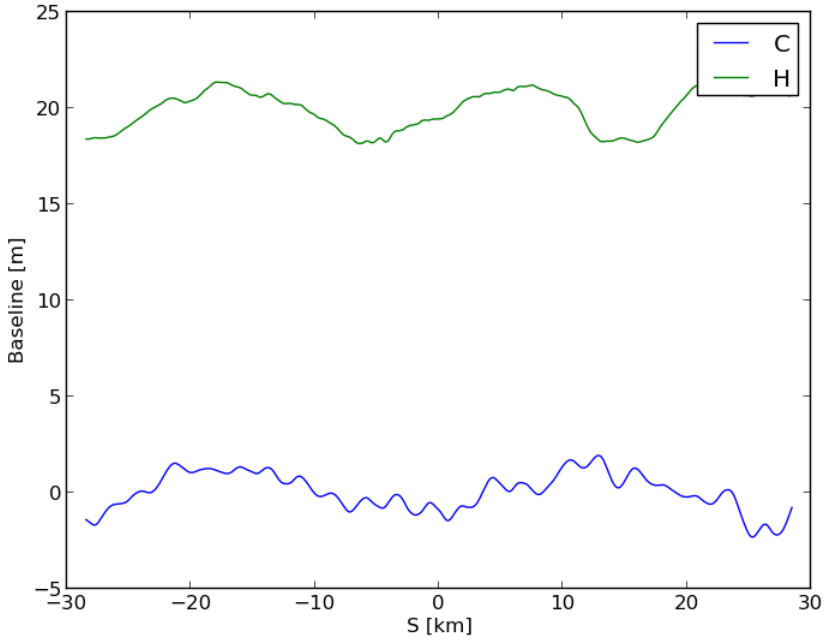
$$\Delta s \approx r\frac{\partial}{\partial s}\left(\Delta\vec{b} \cdot \hat{l}\right)$$

Accumulate to achieve consistent stack

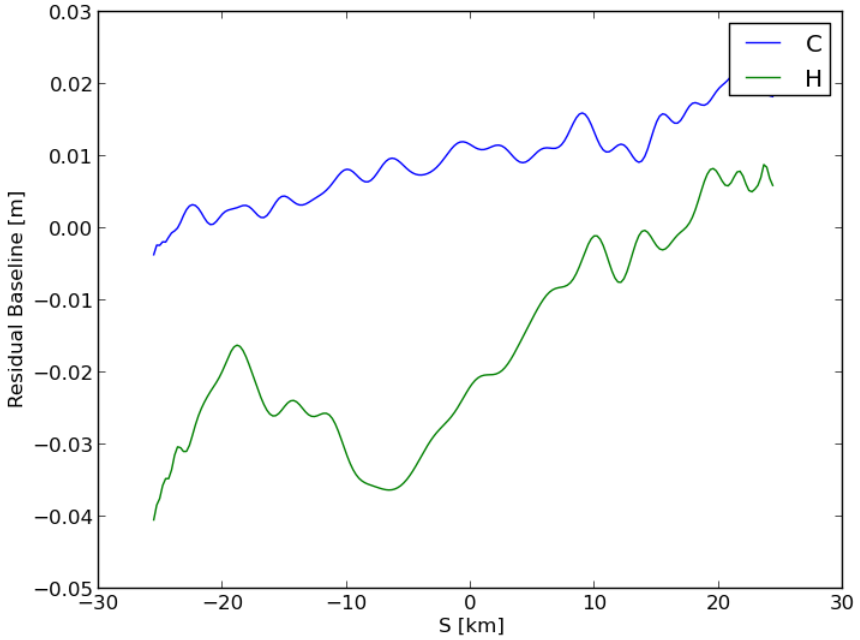
$$\Delta\vec{b}_n = \sum_{i=1}^{n} \Delta\vec{b}_i$$

Step 1: Invert pixel offsets for baseline and reprocess

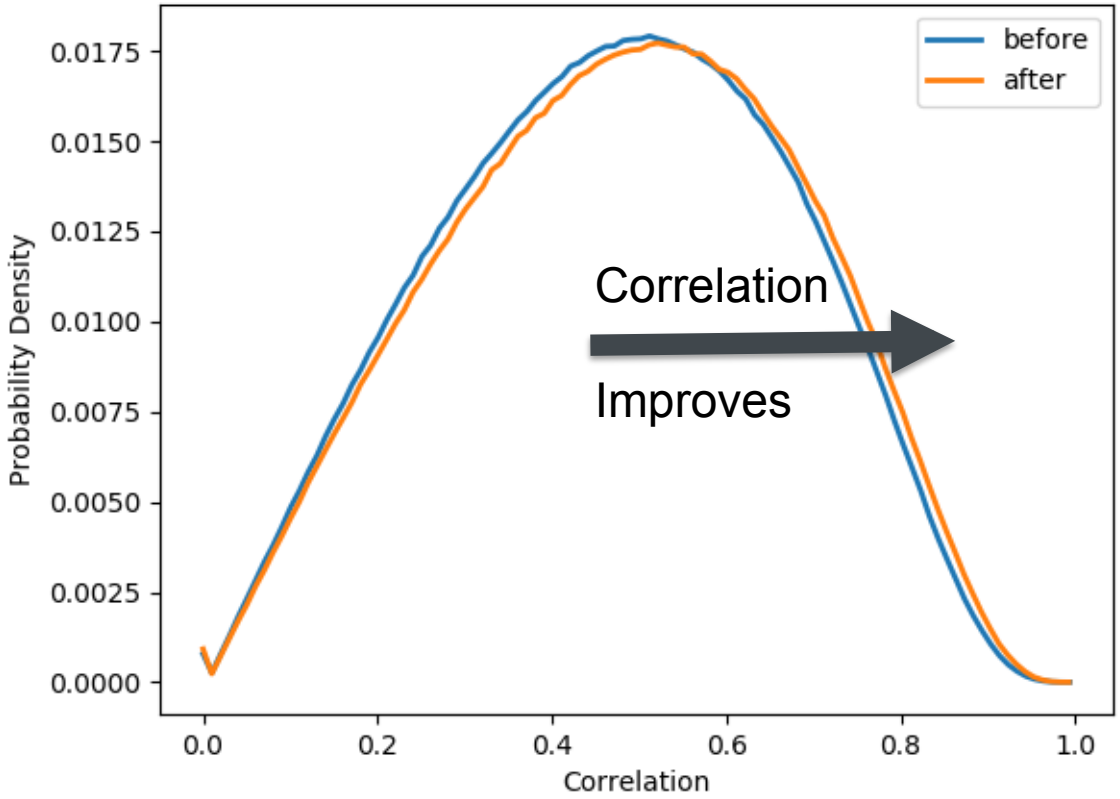
Nominal Baseline of 20 m



Corrections of a few cm



Step 1: Invert pixel offsets for baseline and reprocess



Sometimes residual phase remains

Step 2: Refine solution with phase linking approach

- Advantages
  - Phase is much more sensitive than incoherent cross correlation for UAVSAR.
  - All N(N-1)/2 pairs considered, not just (N-1)
- Disadvantages
  - Phase is ambiguous
  - Possible coordinate rotation

Step 2: Refine solution with phase linking approach

- Phase linking: Find reduced set of (N-1) phases most consistent with observed interferograms.

$$\vec{\phi} = \arg\max\ f(\vec{\phi})$$

$$f(\vec{\phi}) = \sum_{nm} w_{nm} \cdot \langle S_n \cdot S_m^* \rangle \cdot \exp(j(\phi_n - \phi_m))$$

$$\phi_0 = 0$$

Step 2: Refine solution with phase linking approach

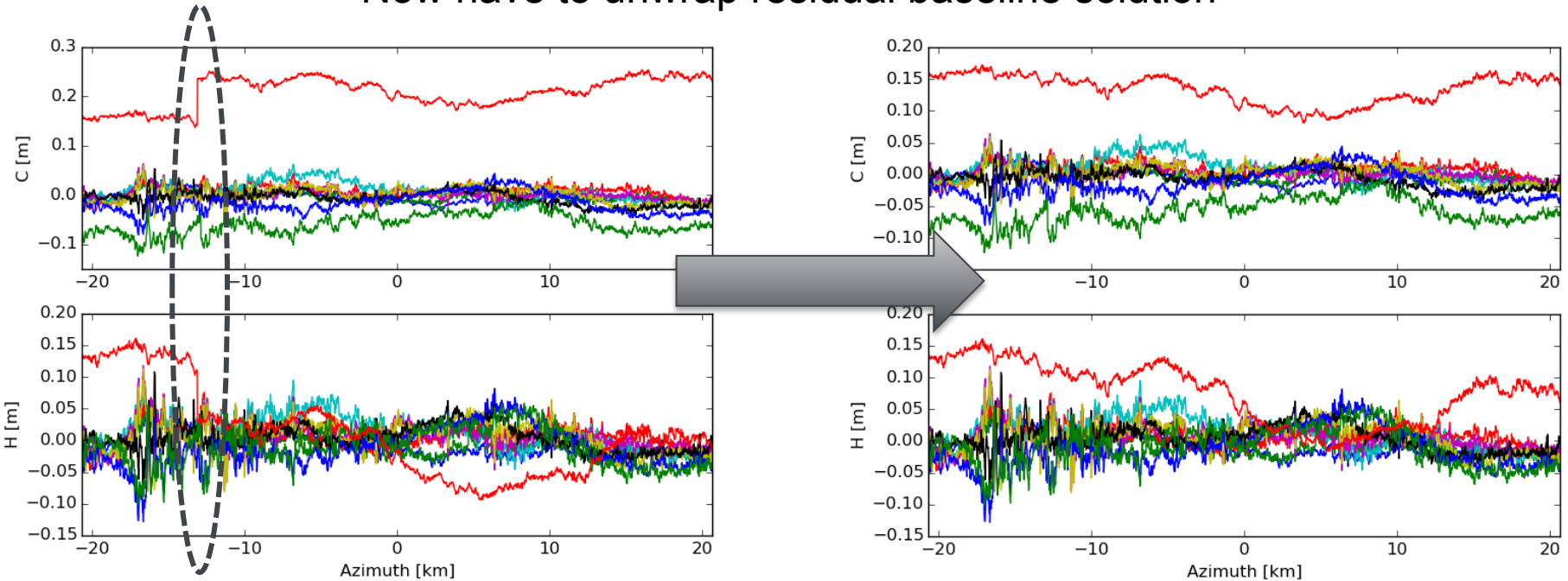
- Weights w_{mn} privilege adjacent pairs
- Model linked phases as baseline and effective DEM errors.

$$\phi_n = \frac{4\pi}{\lambda} \Delta \vec{b}_n \cdot \hat{l} - k_{z_n} \Delta z$$

- Inversion requires diversity of look directions and baselines. Iterative solution.

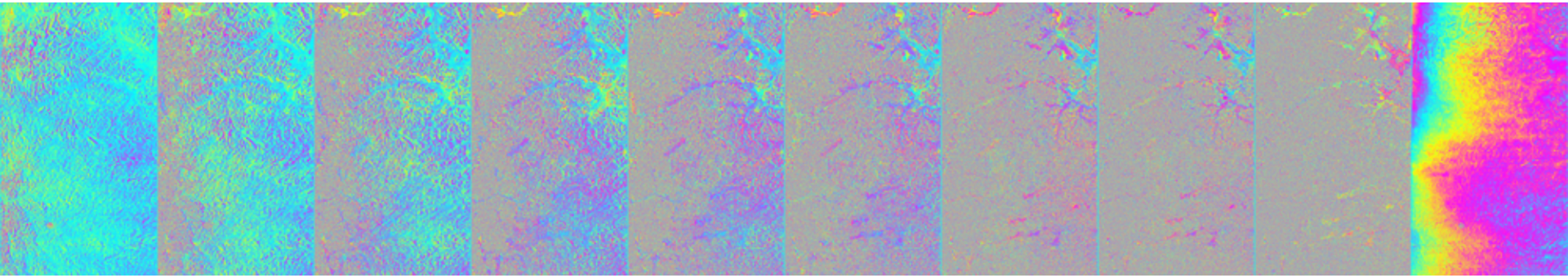
Step 2: Refine solution with phase linking approach

Now have to unwrap residual baseline solution

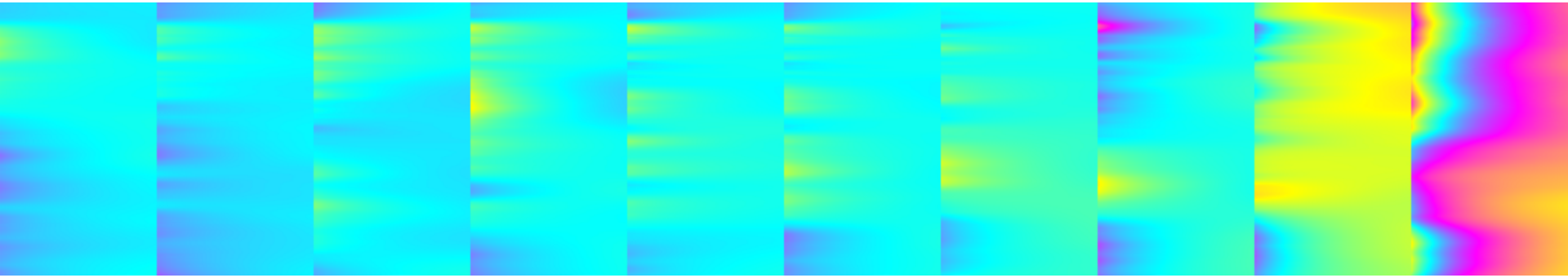


Step 2: Refine solution with phase linking approach

Linked Phases

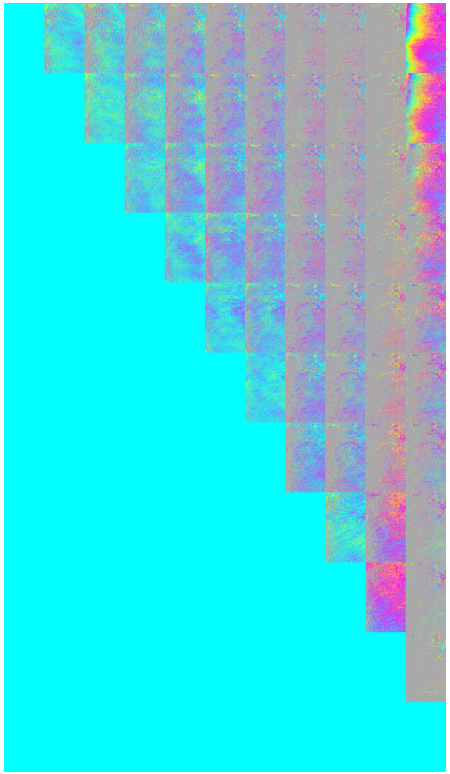


Phase Screens

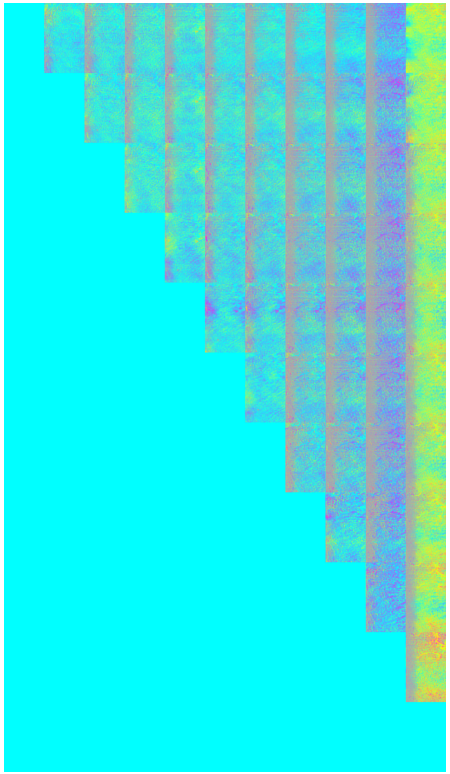


Step 2: Refine solution with phase linking approach

Before



After



Much improved interferogram network

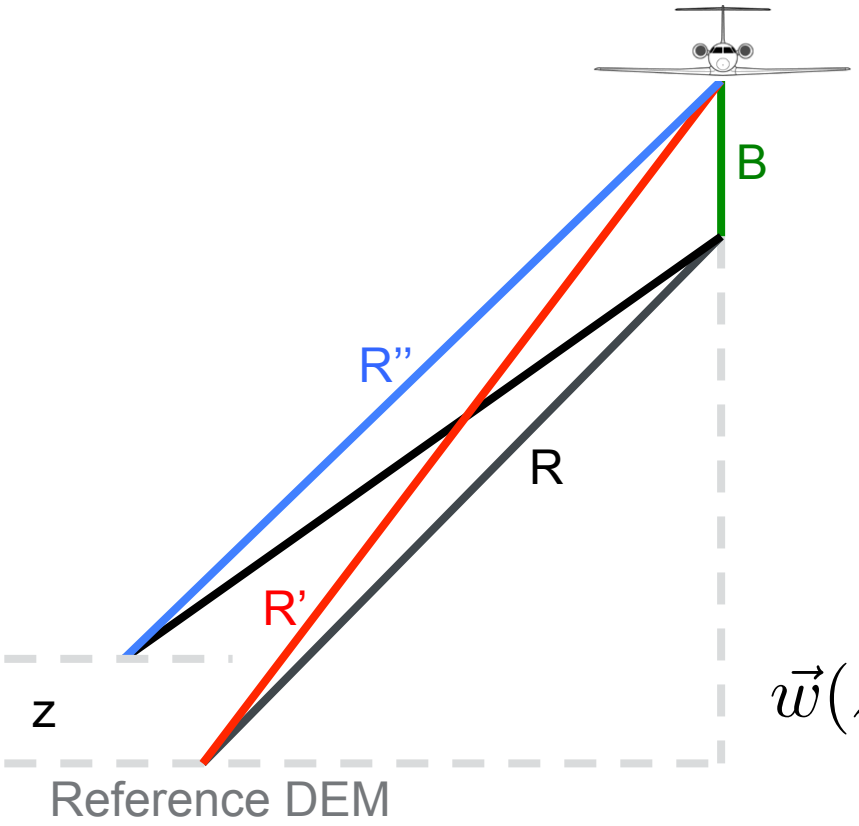
-π +π

Tomogram Formation

- Once phase is calibrated, tomogram formation is easy. If you
  - Ignore range cell migration
  - Assume linear height sensitivity (k_z)

- Then it's just a Fourier transform, beamforming, etc.

Tomogram Formation



Phases

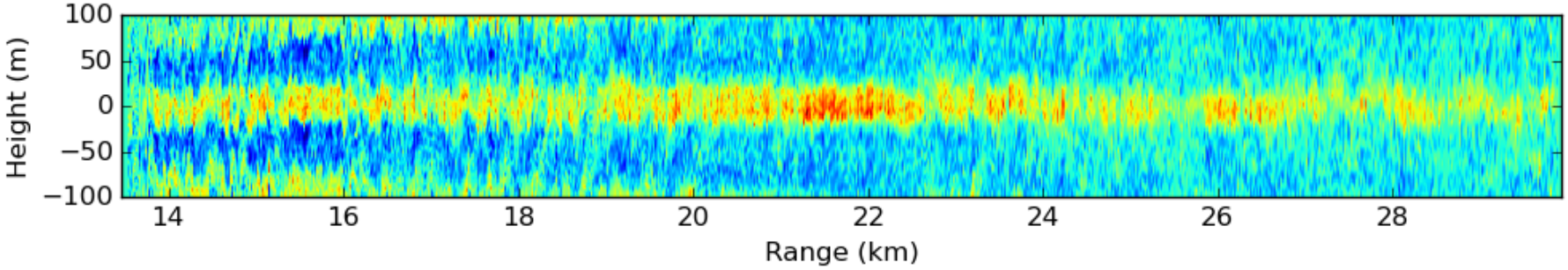
$$\phi(z) = \frac{4\pi}{\lambda}(R'' - R')$$
$$\approx k_z z$$
$$\approx -\frac{4\pi}{\lambda}\frac{B}{R}z$$

Spatial Filter

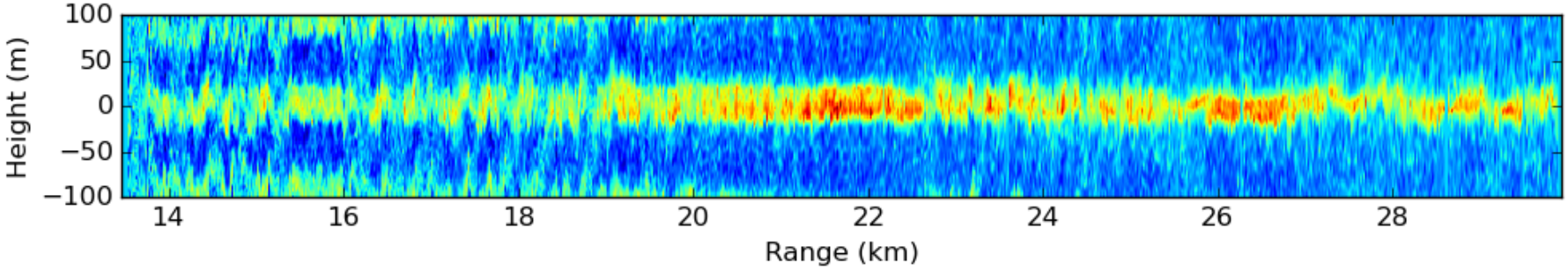
$$\vec{w}(z) = [1 \ \exp(j\phi_2) \ ... \ \exp(j\phi_N)]^{\mathsf{T}}$$
$$P(z) = \vec{w}^H \mathbf{C} \vec{w}$$

Tomography: Rabi Forest

Before Phase Calibration

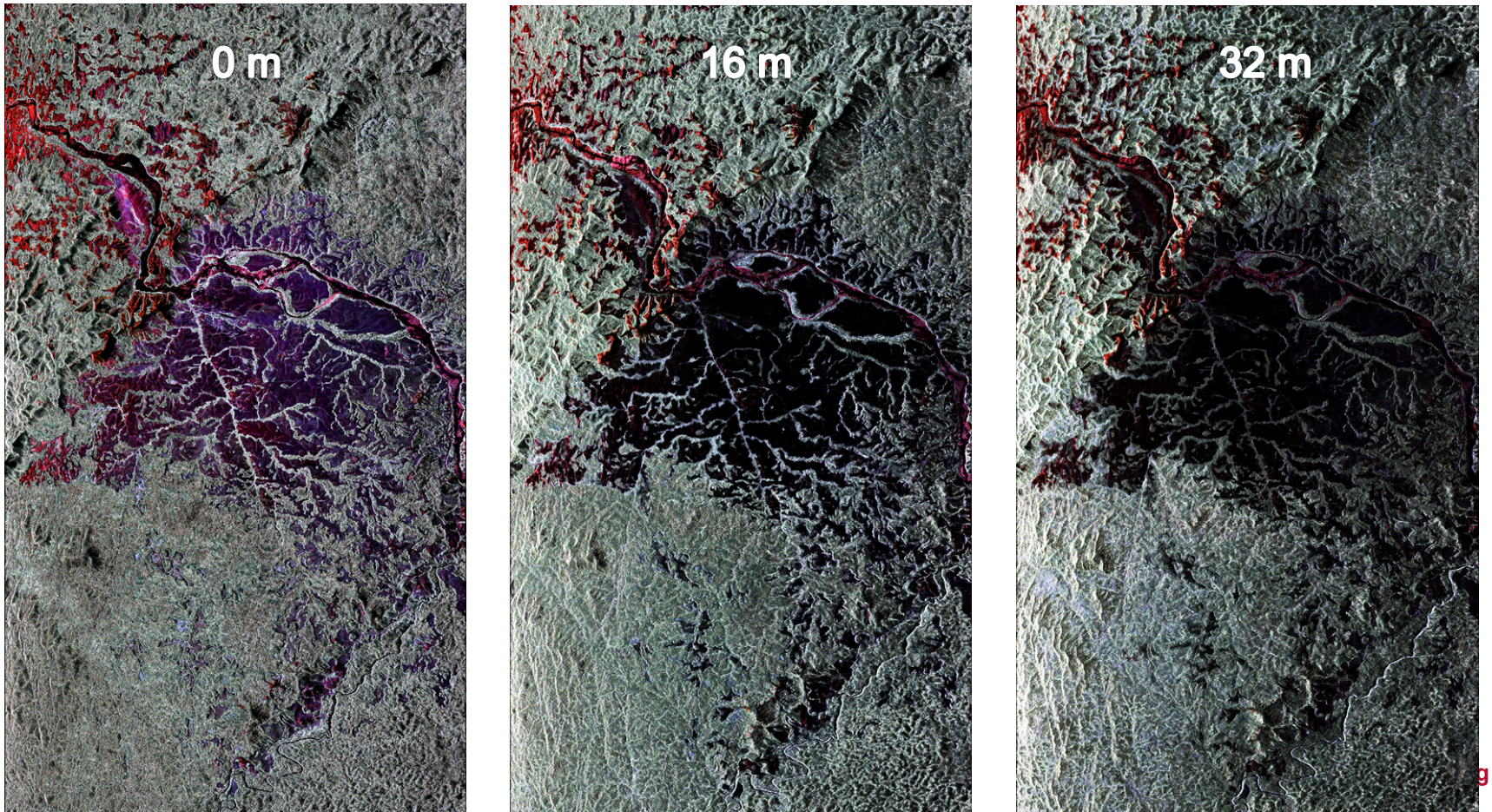


After Phase Calibration



Tomography: Lopé National Park

HH+HV
HH-HV
HV



gov

Data Available Online

- Lopé
  - https://uavsar.jpl.nasa.gov/cgi-bin/product.pl?jobName=lopenp_TM140_03#data
- Rabi
  - https://uavsar.jpl.nasa.gov/cgi-bin/product.pl?jobName=rabifo_TM130_01#data

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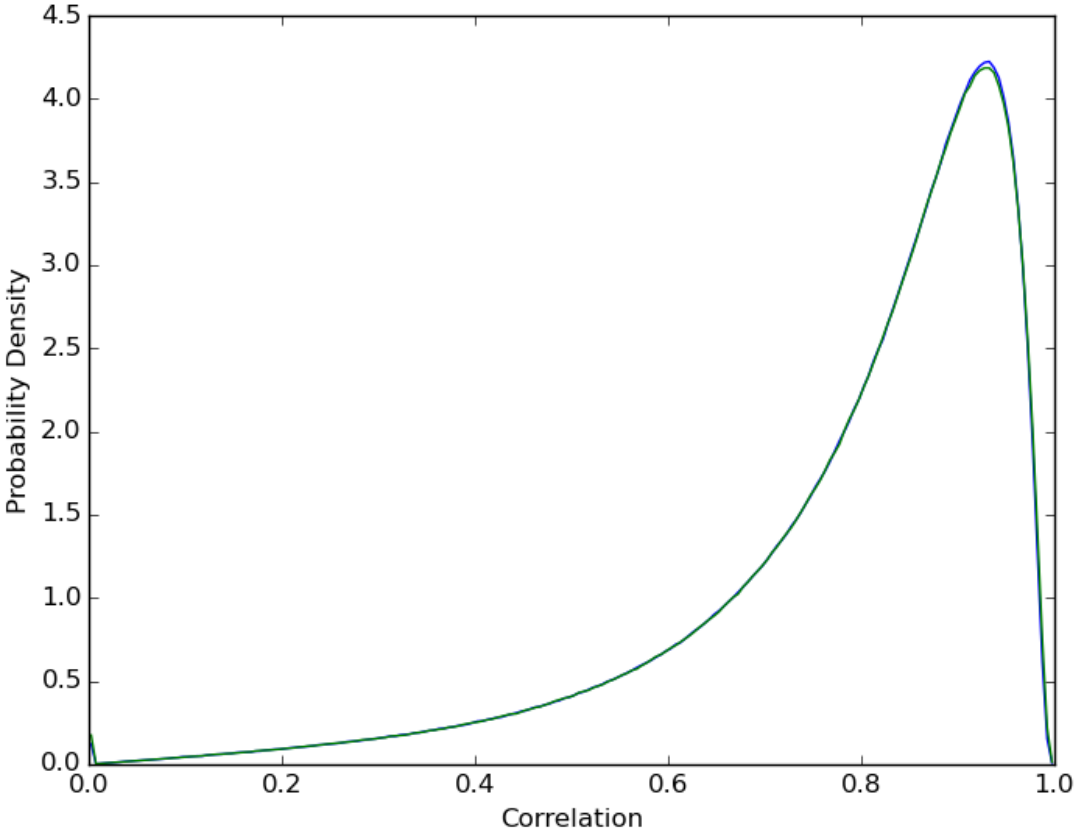
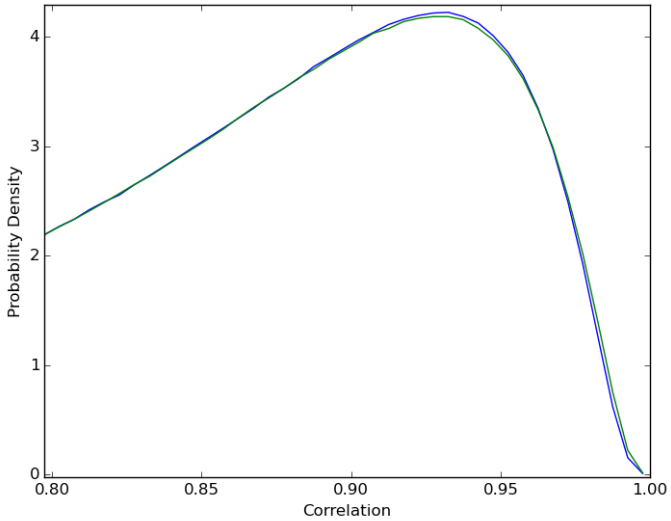
Backup

Correlation improvement for Rabi Forest





Marginal improvement for Flight 16010 takes 000 and 001.